Brief Description of the Drawings

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG 1 is a side view of an electricity generating apparatus according to a first embodiment which includes showing the lift and drag force vectors resulting from the wind induced main rotor's thrust vector;

FIGS 2 and 3 show a front view of the apparatus of FIG 1 having one, two and three tethers respectively;

FIG 4 shows a side view of an electricity generating apparatus according to a second embodiment;

FIG 5 shows a front view of the apparatus of FIG 4;

FIG 6 shows a perspective view of an electricity generating apparatus according to a third embodiment; and

FIG 7 shows an array of the apparatus of FIG 6.

Nomenclature Used in FIGS 1 to 6

A Attachment point of tether in the airframe
D Drag vector
G Center of gravity of craft
L Lift vector
T Main rotor's thrust vector
V Direction of the wind's velocity vector
X,Y,Z Fixed frame of reference
Ø Craft's pitch angle relative to the wind vector

Descriptions for Numbered Annotations in Drawings:

1. Airframe
2. Dynamo(s)
3. Main rotor
4. Torque balancing rotor
5. Single tether cable
6. Swash plate or similar mechanism to tilt the rotor's thrust vector and/or for controlling the collective pitch on the main rotor blades
7. Horizontal stabilizer
8. Vertical stabilizer
9. Two tethers attached to the forward region of the airframe (shown as broken line)
10. One extra tether attached near the centerline of the platform (shown as broken line)
11. Ground winch or winches
12. Parachute and its housing
13. Twin rotors in contra-rotation
14. Wind sensor to ascertain direction of wind relative to craft
15. Auxiliary tethers attached adjacent to rotor thrust lines
16. Single tether attached near the centerline of the platform (shown as broken line)
17. Confluence point
18. Four rotors
19. Four auxiliary tethers
20. GPS receiver units for craft's pitch determination
21. GPS receiver units for craft's roll/yaw determination

Amended Paragraphs in Patent Application No. 10/064,806 ROBERTS ET AL

Please Note: The following paragraphs to be amended use the paragraph numbers in the patent application publication. A section on drawings is being submitted on separate sheets which should appear after paragraph 0009 but the paragraph numbers herein after paragraph 0009 are **not** advanced to reflect the drawing paragraphs addition. (The original submission did not include drawings). The amended paragraphs are in "marked up" format.

[0002] Examples of methods in this field previously described include a paper entitled "Electricity Generation from Jet Stream Wind" by Fletcher and Roberts, appearing in the July-August 1979 issue of the Journal of Energy of the AIAA; a paper entitled "Tethered Gyroturbine Wind Energy System" by Noll and Ham delivered at the 2nd Wind Energy Innovation Systems Conference in Colorado Springs, Dec 3-5, 1980; U.S. Patents 4,572,962 and 4,659,940 by Shepard; and numerous papers by the above Bryan W. Roberts. Roberts is the only one known to us who has actually flown a Flying Electric Generator(FEG) ~~an FEG~~ in open air and generated power. ~~Roberts and Shepard are responsible for the new invention covered below.~~

[0003] The above Paper by Noll and Ham is believed to constitute one of the first suggested uses of a tethered rotorcraft to capture and transmit high altitude wind energy to the ground, and this paper did contemplate use of a single tether. But it did not address certain aspects necessary for practical operation. As of this time, no apparatus capable of generating power from high altitude winds is known to be in operation. But, as above, Bryan Roberts, of the instant invention, did design and test a rotorcraft which generated power in 1986-87 in Australia flying sixty feet above a field, using tethers returned to separated points on the ground. ~~This rotorcraft, at least in principle, could have been flown at much higher altitude.~~

Detailed Description of the Preferred Embodiments

[0010] In the preferred embodiments of this invention described below, rotorcraft apparatus is held aloft with stability where using one, or a plurality, of revolving rotors are incorporated into a tethered platform that is entirely supported by the interaction of the said rotors with the wind. The platform is tethered with one, or a plurality of parallel tethers, which may incorporate electrical conductors for transmission of the electrical energy produced by the interaction of the rotors with the wind.

[0012] A single rotor platform (FIGS 1 to 3) is one comprised of one main and one dynamo in an airframe. A plurality of dynamos driven by the rotor may be used. To this airframe is also attached a generally smaller rotor, or similar thrust producing device, for the purpose of balancing or reacting the torque produced by the main rotor during the generation process. This torque reaction rotor is normally placed in a plane at right angles to that of the main rotor.

[0025] An alternative arrangement may be used using two tethers (FIG 3) instead of one as described above. When using two tethers these are attached to the platform at points lateral to the main rotor. In this manner the lateral thrust tilting action on the main rotor (i.e. function 3 above) may be eliminated. By addition of one more extra tether (i.e. now making three in all) to an attachment point in the forward region of the platform then the fore and aft thrust-tilting function (i.e. function 2. above) may be deleted. In this latter case, the roll and/or pitch of the platform, relative to the fixed frame, may be controlled by lengthening or shortening one or more of the above mentioned three tethers. These tethers would be essentially parallel issuing from three winches normally located at a single point on the ground. By differential shortening or

lengthening the tethers the craft can be controlled in pitch and/or roll. Height and/or range would be controlled by collectively shortening or lengthening all of the three tethers.

[0028] A twin rotor platform (FIGS 4 and 5) is one comprising two preferably identical contra-rotating rotors with one or a plurality of dynamos. In this case no torque balancing methods are required. The rotors are mounted with their axes parallel and preferably disposed laterally relative to the prevailing wind vector. The rotor axes may be inclined at small angles of dihedral or anhedral to enhance the platform stability, if desired. In addition, the twin rotors can be mounted in an in-line configuration instead of being mounted laterally. While the in-line, or tandem, configuration is not preferred, it is workable.

[0044] A four rotor configuration ~~and its control has been defined in a recent Australian Provisional Patent, PR8712, entitled Windmill Kite, lodged 7th November 2001in the name of Roberts. These rotors are~~ is arranged in a two by two square or rectangular configuration. ~~The current patent application acknowledges this and particularly the fact that the above provisional application~~ It requires no fore and aft or lateral tilting of the thrust vector on any of its four rotors.

[0045] The invention described herein as applied to a four rotor configuration (FIG 6) is directed towards a platform control strategy that ensures the correct orientation and location of the platform in any chosen portion of airspace using a single tether. This tether is attached to the platform at a single attachment point. In addition, the current invention embraces an optional improvement involving the use of four auxiliary tethers. These auxiliary tethers extend from four attachment points adjacent to the thrust lines of each of the four rotors. The four auxiliary tethers, or any other number of auxiliaries, extend downwards to a single confluence point located below the platform as described earlier. The object of the four short auxiliary tethers is to reduce the bending moments in the platform's airframe and thereby reduce the overall weight of that airframe.

[0046] In all the rotor configurations power is derived from the wind by tilting the rotorcraft at an angle which will permit the rotors driven by the wind to both support the rotorcraft and its tether(s) and transmitting the available remaining energy to the ground as shown by the lift and drag force vectors of FIG 1, the power generation being associated with the drag vector. The formula for what angle to assume at each different wind velocity and altitude is determined by differing characteristics of each rotorcraft configuration. The angle commanded, whether from on-board logic or ground computer, is based on stored formulae. Power is normally transmitted to the ground using high voltages, such as around fifteen kilovolts (15kV) when operating at an altitude of 15,000 feet. This is to save conductor weight by using low currents. While tether strength and weights, including conductors and insulation, are critical design elements, newly available cord materials have extremely high strength to weight ratios, and the other needed elements are also commercially available to meet the needed tether requirements

[0047] Existing position of a rotorcraft relative to a ground frame of reference may be determined automatically by means such as radar, Global Positioning System (GPS), Carrier Phase Differential GPS (CDGPS) or inertial navigation technology. Historically, gyroscopic means have been used to keep track of current pitch, roll and yaw attitude information. However, if the positions at different locations on a rotorcraft are determined with sufficient precision, the attitude aspects of pitch, roll and yaw may also be determined by combining this positional information. For example, the pitch may be determined from the difference of altitude at extreme positions fore and aft on the rotorcraft by the GPS receiver units (FIG 6 annotation 20).

[0050] For example, in a typical array layout(FIG 7), a line of winches perpendicular to the prevailing wind for that location may be established. Then substantial variation of the wind direction, such as forty five degrees in each direction, may be accommodated simply by close computer control of the FEG positions without moving the winches. Statistically, at most locations,

this variation is sufficient to have negligible loss of energy due to unusual wind direction. In some locations, however, winches may be moved as conditions dictate.

[0053] As a matter of safety, it must be assumed that a tether may be severed or break in spite of design strength safety factors. This opens the possibility that the wind will carry an FEG beyond its prescribed operating limits. As the FEGs fly at considerable altitudes, sufficient potential energy due to this altitude will normally be available to permit an FEG to be guided back to its winching point in spite of the wind, although that is not described here. However, as an emergency measure, a well-known method may be used which utilizes two parachutes (see note 12 in FIG 3), not dissimilar, in principle, to the system used for the Solid Rocket Booster (SRB) recovery phase on the Space Shuttle. In this method, the first parachute is small, which makes the apparatus descend very rapidly until just above ground level, at which time the second much larger parachute opens to permit a soft landing. It is thus possible to ensure that the craft will not reach ground beyond its prescribed limits.